

THE CELSS BREADBOARD PROJECT: PLANT PRODUCTION

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INTRODUCTION

I will describe NASA's Breadboard Project for the CELSS program. For those familiar with the Breadboard Project at Kennedy Space Center, it should bring you up to date on what has happened during the last year; for the others, it will be a short introduction to the project.

The simplified schematic of a CELSS is shown in Figure 1. I start with the schematic to emphasize that we are taking a modular approach to constructing the CELSS Breadboard. We are researching each module in order to develop a data set for each one prior to its integration into the complete system. I will concentrate on the data being obtained from the Biomass Production Module or the Biomass Production Chamber. The other two primary modules, food processing and resource recovery or waste management, will be discussed only briefly. The crew habitat module will not be discussed at all during this presentation.

The primary goal of the Breadboard Project is to scale-up research data to an integrated system capable of supporting one person in order to establish feasibility for the development and operation of a CELSS. Breadboard is NASA's first attempt at developing a large scale CELSS. Research emphasis in our work over the past three years has been on the Biomass Production module. In late 1990 integration of the food processing and resource recovery modules will be initiated. The goal is to have a complete functional system operational by 1993. The crew habitat module will only be simulated during the Breadboard Project.

BIOMASS PRODUCTION MODULE

Biomass Production Chamber:

The Biomass Production Chamber (BPC) is a 7.5 meter tall by 3 meter in diameter stainless steel cylinder (Figure 2). This cylinder or chamber is oriented in the vertical position and has an internal volume of 113 m³. The chamber itself was used for leak testing of capsules during the Mercury space-flight program. We renovated and modified it so that it could be used as a large atmospherically sealed plant growth chamber.

The chamber is divided in half by a floor making it a two story structure. An extensive air distribution and conditioning system was added to the outside of the chamber. Eight racks were built and installed on each of the two floors in the chamber. Each stainless steel rack has two light banks with a shelf under each to accommodate plants during their growth. Air flow in the chamber is across the plant canopy and back through the light banks into the duct system. Lighting in the chamber is by high pressure sodium lamps and at full intensity is approximately one half full sunlight. Environmental control for each floor or compartment of the chamber is separate. A steel platform was built around the chamber in order to allow access to the chamber and to the ducting around the outside.

In the control room for the BPC is housed a microprocessor that is programmed through a computer station to control conditions in the chamber. A fundamental principle followed in construction of the control and monitoring system was that

the control system would be separate from the monitoring system. Therefore, each system has its own sensors and computer. The primary components controlled and monitored from this room are nutrient delivery, environmental parameters and atmospheric gases. All data collected are stored in a central main frame computer.

All data collected can be displayed on any computer in the facility in both graphic and tabular form. Digital displays in the control room give current readings for any parameter being measured in the chamber. Visual and auditory alarms are activated when any parameter goes out of range during chamber operation. The interior of the chamber is under constant surveillance by television cameras. One camera on each floor has a pan-tilt-zoom capability which allows one to inspect for leaks or

other problems in the chamber and to make close-up observations of the plants from outside the BPC.

The atmospheric gas system can control and monitor up to four gases. Currently we are monitoring oxygen and carbon dioxide and are controlling carbon dioxide. Gas control is accomplished by the introduction of the appropriate gas from pressurized cylinders located outside the chamber. A system of valves and switches in the gas racks allows control of gases at the requisite levels. Monitoring of trace gases is accomplished through gas chromatography and mass spectrometry of samples taken from the chamber. Additional gas control and/or monitoring capability will be added to the BPC as requirements are identified.

The nutrient delivery system is another major component controlled and monitored in the BPC. This system is made up of four large nutrient solu-

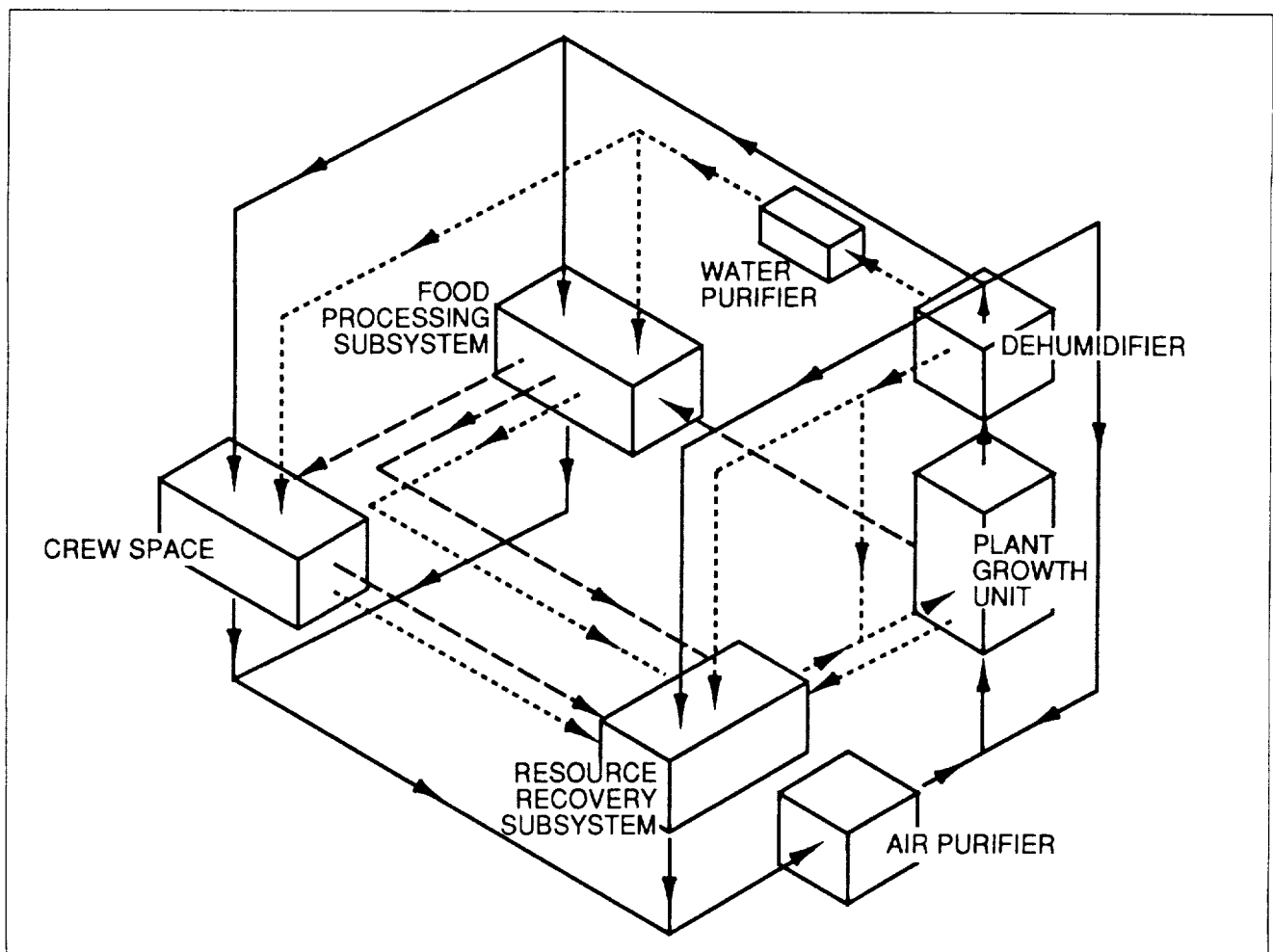


Figure 1. Schematic CELSS System Diagram

tion holding tanks outside of the chamber and 64 plastic plant growing trays inside of the chamber. The 64 growing trays are divided between four levels, 16 trays per level, with each level receiving solution from one of the four storage tanks. All plants are grown in thin film hydroponics. Nutrient solution is delivered to the back of each tray, flows across the bottom of the tray, and returns to each nutrient tank through a common guttering system. This system is obviously dependent on gravity for its operation. We monitor flow rate, pH, conductivity, and liquid level for each of the four tank systems. Samples are removed periodically from each tank so that inorganic chemical and microbial analyses can be conducted. Currently, pH and liquid level are the only parameters being actively controlled in this system.

Wheat Productivity Test:

We have conducted several trials of wheat in the

Biomass Production Chamber. The crop growing area for each level in the chamber is approximately 5 sq meters which makes the total growing area of the chamber approximately 20 sq meters. Wheat is the first crop on which we have completed tests in the BPC. These tests have concentrated, as will future research, on measuring mass flow through, energy input to, and contaminant buildup in the system. During each test, we are continually monitoring CO₂, oxygen and water in the system in order to determine flow rates through the plant canopy. Energy input is also measured so that the demands of the system can be determined. All crop tests in the BPC are conducted from the seed stage to full plant production.

Carbon dioxide is continuously monitored through each test. It is controlled at 1000 ppm during the test period. The 1600 ppm peaks that show up periodically occur when the lights are off in the chamber. Such fluctuations in carbon dioxide due to the presence or absence of active photosyn-

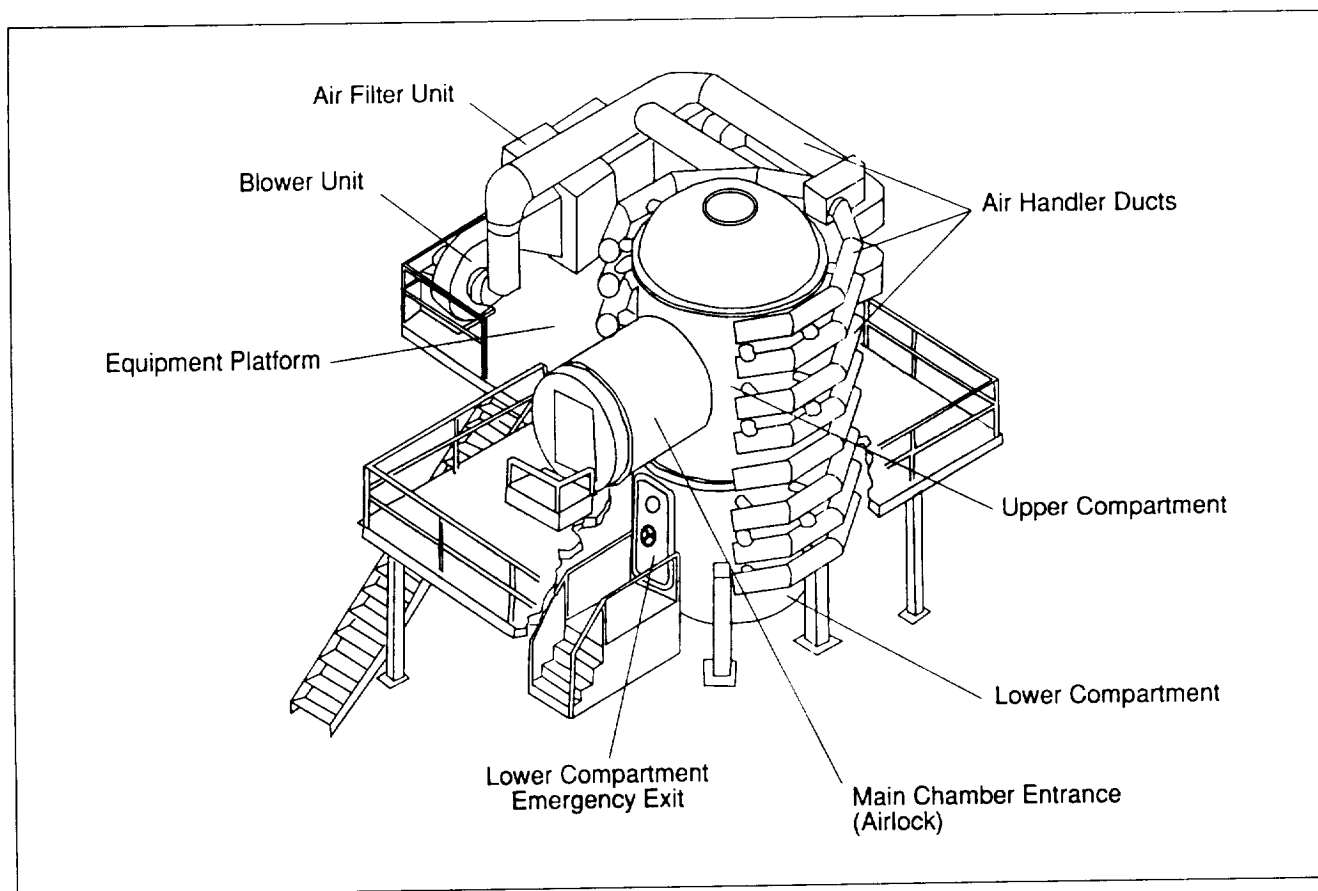


Figure 2. The Biomass Production Chamber.

thetic activity must be taken into consideration when one is designing a CELSS. We have measured the rate of carbon dioxide uptake in the chamber when there is a full canopy of photosynthetically active plants. During these trials, the chamber's carbon dioxide level is elevated to a set point, then the valve controlling CO₂ input into the chamber is closed. The rate that the carbon dioxide is drawn out of the chamber indicates the photosynthetic activity of the crop under the existing environmental conditions. One can change parameters such as temperature and irradiance levels in the chamber during these tests and observe the corresponding changes in photosynthetic rate. We have data on the amount of CO₂ used on a daily basis throughout an entire wheat life cycle. We have examined photosynthesis and respiration data for a mature crop of wheat on a meter sq per second basis. Manipulating temperature and irradiance levels impacts photosynthesis and/or respi-

ration rate in the mature wheat canopy. One could utilize these effects, for example, in regulating a CELSS for optimum uptake of carbon dioxide. We have also determined the light compensation point for this canopy of wheat, the total uptake of carbon dioxide by the wheat in the chamber on an hourly basis and how carbon dioxide levels influence transpiration rates. All gases added to the BPC during tests are metered in through mass flow valves.

During all crop tests there is a set of environmental parameters that are constantly measured and recorded. During the wheat trials these included irradiance levels, relative humidity, temperature and atmospheric pressure which are routinely measured during each test of a crop. Parameters measured in the nutrient delivery system include flow rate, liquid level, pH and conductivity. In addition, the amount of condensate water collected from each of the two compartments on a daily basis is measured and recorded during each

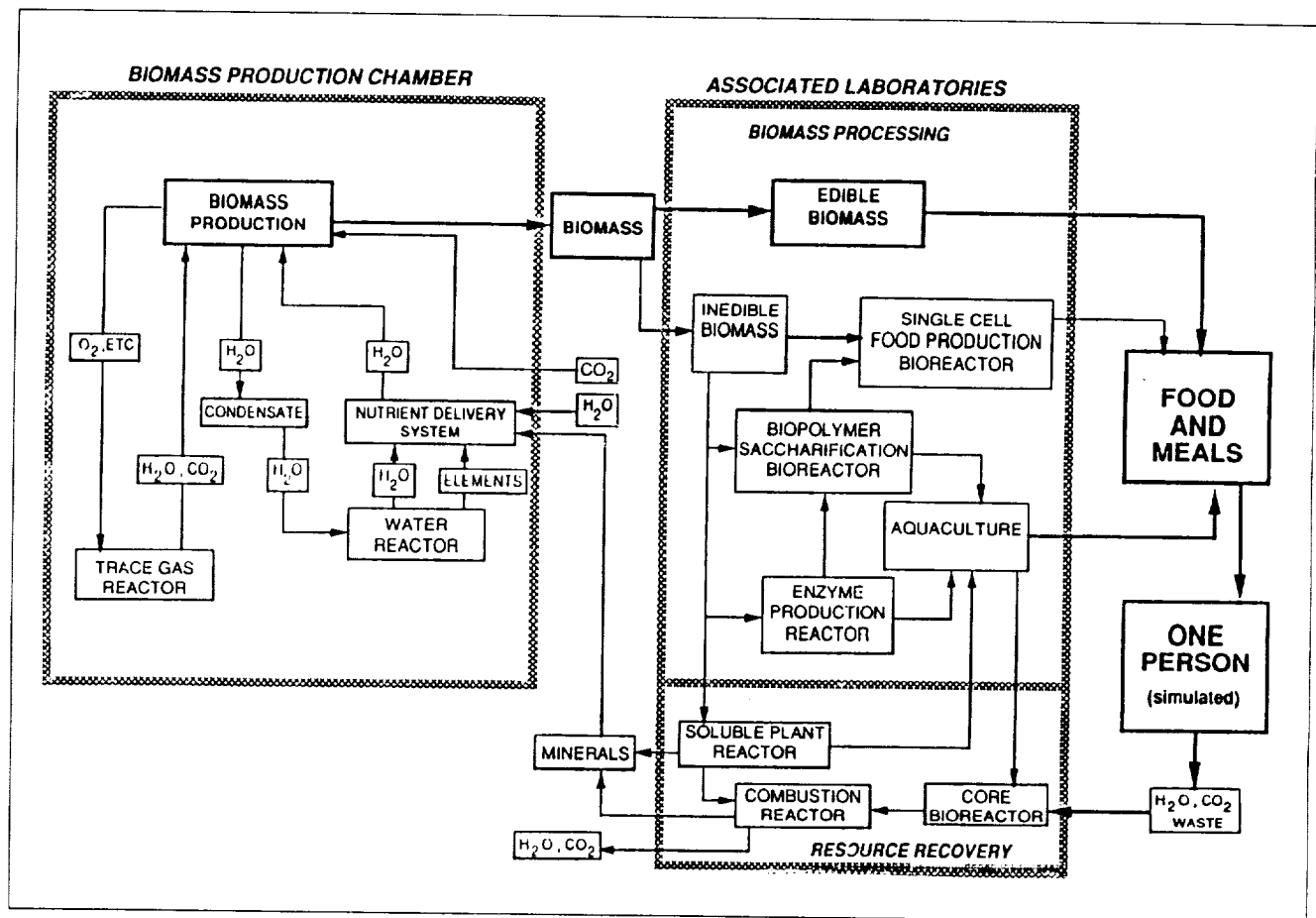


Figure 3. CELSS Breadboard Concept.

trial. The composite of these environmental data, the photosynthetic gaseous exchange data presented previously, and the measurement of biomass production allows one to begin to understand the operational requirements of a Biomass Production Module, at least for wheat.

When measuring mass flows through a system and determining rates of contaminant buildup, one must continually measure the leak rate of the facility being used. A decay curve for carbon dioxide over a 48 hour period of time from an empty but operating Biomass Production Chamber shows a slow decline of carbon dioxide which when mathematically analyzed allows a determination of the chamber leak rate. The best leak rate which we have measured is 2.5% of the chamber volume leaked per day. The average leak rate for the operation of the Biomass Production Chamber is approximately 5% of the volume leaked per day. We are continually sealing the chamber during each operation to improve our atmospheric leak rate.

CANDIDATE CROP SPECIES

A variety of crop species are currently being prepared for testing in the BPC. These tests are being conducted in conventional plant growth chambers located within the Life Sciences Support Facility at Kennedy Space Center. The next crop to be tested in the Biomass Production Chamber will be soybean. Preliminary research on this crop has centered on response of the soybean to various irradiance levels and elevated carbon dioxide concentrations. Potatoes will be studied in the BPC next year. We have already grown two varieties in thin film hydroponics. Both white potatoes and sweet potatoes have formed tubers and storage roots, respectively, in the hydroponic system. Other plant species being prepared for testing in the BPC include: peanuts, lettuce, radishes, tomatoes, sugar beets, bush beans, and rice. Data generated on each of these crop species by the research program will be utilized in preparation for growing these plants in the Biomass Production

TASK	ACCOMPLISHMENT				
	FY 89	FY 90	FY 91	FY 92	FY 93
CROP PRODUCTION	Wheat	Wheat, Soybean	Wheat, Soybean, Potato	Multiple Crops	Continuous Production
WATER RECYCLING	Design	Fabricate And Install	Operate	Modify	Operate
ATMOSPHERIC GAS CONTROL	Measure And Analyze	Design and Fabricate	Install	Operate	Operate
BIOMASS PRODUCTION CHAMBER					
ADJACENT LABORATORIES					
BIOMASS PROCESSING	Harvest, Store Measure, Analyze	Establish Laboratory	Process Edible	Process Inedible	Evaluate
RESOURCE RECOVERY	Store, Measure Analyze	Establish Laboratory	Recycle minerals, Design Combustion System	Install	Evaluate
DATA MANAGEMENT	Environmental Nutrient Delivery, Atmospheric	Energy, Trace gas	Multivariate Analysis	Models	Validate

Figure 4. CELSS Breadboard Project Matrix.

Chamber. Current plans are to test at least five crop species in the BPC by the end of 1993.

SYSTEM INTEGRATION

Figure 3 shows a block diagram of the initial CELSS that we plan to develop and operate during the Breadboard Project. Final integration and initial testing of this system is scheduled for 1993 and 1994. The left hand side of this illustration is of the Biomass Production Chamber. Data being collected from the operation of this chamber include: biomass, amounts of condensate water, elemental uptake, carbon dioxide and oxygen fluxes, microbial constituents, concentrations of trace organics in the atmosphere, and presence of trace organics in the nutrient delivery solution. We are also collecting information on manpower requirements, energy use, spare parts requirements, and operational reliability. The condensate water loop on the BPC will be closed during 1990 and design completed on a trace gas control system if one is required.

The right side of Figure 3 illustrates the components of the resource recovery, biomass conversion, and food processing modules to be incorporated from 1990 through 1992. These functions will be conducted in laboratories adjacent to the BPC. Analytical chemistry and microbial diagnostic laboratories will also be included in this space. Food processing activities will concentrate on producing a variety of meals from a few crop species. Equipment required to process the edible plant material will be developed and/or tested in conjunction with BPC operations. Biomass conversion activities will concentrate on cellulose conversion of the inedible part of the plant biomass. Subsystems to be tested for this conversion include: enzymatic digesters, single cell protein reactors, and aquaculture. Resource recovery activities will concentrate on the conversion of the final unused material in the system into an acceptable nutrient solution for the plants. Subcomponents to be tested in this effort include: a leachate reactor for the plant biomass, a microbial reactor, and an oxidation/combustion reactor as a final element. We are currently conducting some

research into the development of these modules. All resource recovery, biomass conversion, and food processing components will be functionally integrated with the BPC operations. Each sub-component will be sealed as required to develop a mass flow database. Data required to determine system operations for each component including mass flow, energy use, and operational reliability will be collected during all trials. Trials of at least a six months duration will be conducted when the total system is functional. The expected activities to be completed during the next four years are summarized in Figure 4.

SUMMARY

The plant production module (Biomass Production Chamber) of a initial CELSS is currently in operation. Data required to establish the mass flow of carbon, hydrogen, oxygen and nitrogen through this system along with information on energy use and operational requirements are currently being collected. The construction of laboratories to accommodate the resource recovery, biomass conversion, and food processing modules of a CELSS is nearing completion. At least 5 crop species will be tested in the BPC by the end of 1991. All subcomponents of the resource recovery, biomass conversion, and food processing modules should be developed and tested by the end of 1993. Initial feasibility testing of a complete CELSS should be completed during the 1993-1994 time frame. The integration and testing of this complete system will generate numerous questions and problems that will require research to solve. This initial testing of a CELSS is the first step in an iterative process that will ultimately produce a functioning CELSS. Many areas will require the development of basic scientific data and/or new technologies prior to the use of a CELSS for life support during long duration space flight. Research and development of a CELSS will require many years of very intensive research and development. Therefore, these initial efforts must be started now if we ever hope to reach our ultimate goal, the permanent presence of humans in space.